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Correct use and functioning of biomedical equipment in medical teaching through clinical simulation: an action research project.

Uso correcto y funcionamiento de equipos biomédicos en la enseñanza médica mediante simulación clínica: una investigación-acción.

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Summary.

This research investigates how medical students learn the use and operation of biomedical equipment in clinical simulation courses, employing an action research design. Purposive and judgmental sampling was used to select participants, allowing for the collection of diverse experiences related to the phenomenon under analysis. Data was obtained from two non-participant observations, two focus groups, twelve semi-structured interviews, two field notes, and a research journal where reflections, perceptions, and emotions related to the process were recorded. Thematic analysis of the transcribed materials revealed that the combination of progressive pedagogies, direct practice, constant handling of the equipment, observation of professionals using it, and teaching from multidisciplinary approaches promotes student learning. However, limitations were also identified, particularly the persistent separation between theory and practice, which hinders the consolidation of competencies applicable in real clinical settings. Consequently, it is proposed that medical education should move toward strategies that increase interaction with equipment from early stages, while strengthening the integration between conceptual knowledge and practical experience.

Keywords: Use, function, biomedical equipment, learning, medical student, action research.

Resumen.

Esta investigación indaga cómo los estudiantes de medicina aprenden el uso y funcionamiento de equipos biomédicos en los cursos de simulación clínica, empleando un diseño de investigación-acción. Para la selección de participantes se utilizó un muestreo intencional y opinático, lo que permitió recoger experiencias diversas vinculadas con el fenómeno analizado. La información se obtuvo a partir de dos observaciones no participantes, dos grupos focales, doce entrevistas semiestructuradas, dos notas de campo y un diario de investigación donde se consignaron reflexiones, percepciones y emociones del proceso. El análisis temático de los materiales transcritos evidenció que la combinación de pedagogías progresivas, prácticas directas, manipulación constante de los equipos, observación de profesionales en su uso y la enseñanza desde enfoques multidisciplinares favorece el aprendizaje de los estudiantes. Sin embargo, también se identificaron limitaciones, en particular la persistente separación entre la teoría y la práctica, que dificulta la consolidación de competencias aplicables en escenarios clínicos reales. En consecuencia, se plantea que la educación médica debería avanzar hacia estrategias que incrementen la interacción con los equipos desde etapas tempranas, al tiempo que fortalezcan la integración entre conocimiento conceptual y experiencia práctica.

Palabras clave: Uso, funcionamiento, equipo biomédico, aprendizaje, estudiante medicina, investigación acción.

1. Introduction

In contemporary medical practice, the use of biomedical equipment is essential to ensuring clinical care in hospitals and health centers. However, a significant problem has been identified: recurring damage to these devices, largely attributable to a lack of skills in their proper handling and a lack of understanding of their operation among medical professionals. This situation not only entails high financial costs for institutions in repair and maintenance (1), but also affects the quality of care (2) and compromises patient safety (3). This scenario highlights a persistent limitation in medical training programs, which have paid little attention to developing skills related to the safe use and technical understanding of biomedical equipment, thus underscoring the need to reconsider its inclusion in curricula.

The inappropriate use of biomedical equipment by healthcare personnel has been identified as a major source of incidents in hospital settings (4). This situation not only impacts patient safety but also significantly increases the costs associated with corrective maintenance, sometimes exceeding the initial cost of acquiring the equipment (5). Although technological advances have transformed clinical practice and contributed to optimizing the quality of care, the rapid increase in the production and availability of biomedical technology presents the challenge of establishing more effective management and maintenance policies in healthcare institutions. These policies aim to ensure the proper functioning of the equipment, extend its lifespan, and contain operating costs (6). In this context, ongoing training for professionals in the correct handling of this equipment is crucial. It allows them to respond to the dynamics of technological innovation and is an essential requirement for ensuring high standards of safety and quality in healthcare.

Various studies have employed pedagogical tools such as clinical simulation (7) and virtual learning environments (8) to strengthen the development of professional competencies in medical students. However, these methods have focused on teaching clinical skills, neglecting the acquisition of knowledge related to the proper use and functionality of biomedical equipment. Furthermore, a gap in knowledge is evident in the academic literature regarding effective strategies for instruction in this specific area. This gap highlights the urgent need for a critical review and the promotion of innovative educational proposals that ensure future physicians possess competent management skills in technologies relevant to clinical practice. This underscores the need to investigate and design didactic approaches capable of effectively addressing this educational challenge. While the literature recognizes the importance of clinical simulation and action research as effective pedagogical approaches in medical education, most studies have focused on the development of clinical skills and medical decision-making, neglecting the analysis of learning related to the correct use and operation of biomedical equipment. In particular, there is little evidence exploring how medical students understand and learn to interact with this equipment within clinical simulation scenarios, as well as how such experiences contribute to bridging the gap between theory and practice. This knowledge gap limits the formulation of specific pedagogical strategies aimed at strengthening competencies in the safe and appropriate handling of biomedical equipment from the initial stages of medical training.

In this context, the present research poses the following question: How do medical students learn the correct use and operation of biomedical equipment in clinical simulation scenarios, from an action research approach? The general objective was to analyze how medical students learn the correct use and operation of biomedical equipment in clinical simulation scenarios, from an action research approach. The specific objectives were to describe the pedagogical strategies employed in teaching the use and operation of biomedical equipment in clinical simulation scenarios, to explore the perceptions and experiences of medical students regarding their learning in the use of biomedical equipment during simulation sessions, to identify the challenges and opportunities that emerge in the teaching-learning process of using biomedical equipment in simulated contexts, and to reflect on the implications of these findings for medical education and the improvement of teaching practices in clinical simulation.

2. Methods

2.1 Research Design

Action research, originally conceived by Stenhouse and later adopted by (9), is presented as a systematic, continuous, and self-regulated academic procedure, grounded in open critique and empirical verification. Within this framework, emphasis is placed on the importance of gathering and examining information, accompanied by reasoned reflection and a critical exchange of perspectives, in order to address situations considered problematic within a specific context. Through a methodical and demanding process with a strong component of self-criticism, this approach not only seeks to broaden the understanding of the phenomena studied in their entirety, but also to foster substantial transformations in the environment in which it is applied.

2.2 Context and participants

The practical activities took place at the Simulation Center of a private university in Bogotá, Colombia. Fourth- and ninth-semester medical students participated, completing their clinical simulation rotations under the guidance of an instructor at the center. Within the framework of this simulated environment research, three non-participant observations were conducted during academic activities related to the medical program and the use of biomedical devices. Each observation lasted approximately two hours and involved five or six students along with a professor. Additionally, a twenty-minute focus group was held with five students, and five semi-structured individual interviews—two with students and three with professors—were conducted, with an average duration of fifteen to twenty minutes. The data were collected at the simulation center, and the total sample consisted of nineteen participants: sixteen fourth- and ninth-semester students and three professors affiliated with the center.

2.3 Research Phases

The four cycles characteristic of action research were developed in a planned and structured manner: first, planning, focused on identifying the problem; second, action, linked to the design of the plan; third, observation, which included its application and analysis; and fourth, reflection, understood as a feedback process (10). Complementarily, and corresponding to these phases, the ADDIE methodology was applied, composed of five stages: analysis, design, development, implementation, and evaluation (11). The relationship between both approaches is represented in Figure 1, which highlights their main correspondences and points of integration. The ADDIE methodology was chosen, but its application was restricted to the design phase. This limitation reflects the need to concentrate greater efforts on the subsequent stages of development, implementation, and evaluation, whose complexity demands a substantial investment of time and resources. In accordance with an action research approach, two work cycles were carried out, specifically corresponding to the analysis and design phases contemplated in the adopted methodology.

Figure 1. Title of the Interaction between the phases of action research and the ADDIE model. Cyclical spiral of action research. Source: Adapted from Latorre (2003).

2.4 Data collection instruments.

The data collection instruments (rubrics, questionnaires, and observation records) were specifically designed for the study context, consistent with the research objectives and the action-research approach. Their development was based on the literature on clinical simulation, medical education, and the use of biomedical equipment, which ensured content validity through theoretical alignment between the instruments and the constructs addressed. Given the qualitative nature of the study, methodological rigor was ensured through criteria specific to this approach, such as triangulation of sources and instruments, internal consistency of the data, interpretive consistency, and the researcher's reflexivity. Furthermore, the convergence of information from different instruments strengthened the credibility of the findings, more so than the application of traditional psychometric metrics typical of quantitative designs.

2.5 Information Analysis

The study combined complementary qualitative and quantitative analyses. The qualitative analysis was conducted using thematic analysis with Quirkos software, focusing on coding, categorizing, and analyzing emerging patterns of meaning from the narrative materials generated during clinical simulation sessions. The consistency of the findings was strengthened through triangulation of sources and instruments, including questionnaires, rubrics, and observation records. Complementarily, the quantitative analysis was limited to descriptive statistics (frequencies, percentages, and measures of central tendency) for exploratory purposes; consequently, the observed variations are interpreted as descriptive trends that support the qualitative analysis, without any intention of statistical inference.

2.6 Ethical Considerations

This study received the corresponding institutional approval, following the technical evaluation carried out by the Research Committee on November 8, 2023. It was also endorsed by the Ethics Committee through act DV0005-2517-CV1814, issued on January 15, 2024, guaranteeing compliance with the ethical principles applicable to research in health education.

3. Results

3.1 Analysis phase.

In the analysis phase of the ADDIE model, developed through an action research cycle, the main needs of the context were identified, the results of which are presented in Table 1. Based on the analysis of the information carried out using Quirkos software, it was possible to group and organize the data obtained according to the previously described data collection tools. This grouping can be seen in Figure 2.

Table 1. Action research cycle in the Analyze phase.

CYCLE	ACTIVITY
Plan	The population was defined as medical students and instruments were designed to characterize their training needs.
Act	These tools were applied and complemented with reflective records in field notes.
Notice	Non-participant observations were conducted at the simulation center to identify difficulties in the teaching and learning of biomedical equipment.
Reflect	The coexistence of various methodologies with different effectiveness was evident, as well as variations in student attitude and performance, which allowed for contrasting pedagogical strategies.

Figure 2. Grouping of information using Quirkos software.

Based on the study of the information, three thematic areas were identified, the synthesis of which is shown in Figure 3.

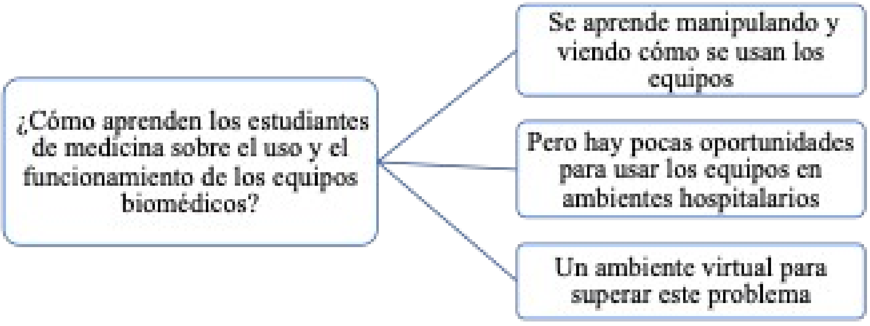

Figure 3. Main themes of the data analysis

3.1.1 Learning occurs by manipulating and observing how the equipment is used.

In the field of teaching biomedical equipment, the analysis made it possible to identify three central dimensions: first, **the pedagogical strategies used by the teachers;** second, **the ways in which students appropriate knowledge;** and third, **the attitudinal dispositions they manifest during their training process,** which together form a comprehensive overview of learning in this specialized field.

3.1.2 Pedagogical strategies used by teachers

It was observed that the instructors employed diverse pedagogical resources, ranging from initial explanations of technical operation to the implementation of practical exercises, either using high-fidelity simulators or with students acting as patients. First, the instructors provided a detailed description of the equipment, addressing its operation, structure, and clinical applications, thus establishing an initial framework for understanding. Subsequently, they explored prior knowledge through open-ended questions to tailor the instruction to the identified learning needs and address any knowledge gaps. Following this, students were guided on the correct connection and handling of the biomedical equipment's accessories, an aspect considered fundamental for its safe use in clinical settings. The physical principles underlying its operation were also addressed, fostering an understanding of its applicability in medical practice. Likewise, the importance of adhering to biosafety measures, such as the use of gloves and other protective equipment, was emphasized to minimize the risk of infection and safeguard both healthcare personnel and patients. The professor incorporated clinical procedure simulations to facilitate learning in a controlled environment. In this experience, a student acted as the patient while tests and measurements were performed using a transducer. Initially, the professor operated the equipment exclusively, but this was gradually transferred to the students, thus promoting their participation and the development of technical skills. A comparison was also made between real clinical images and those obtained using an ultrasound machine applied to a simulated patient, to help students understand their diagnostic value and relevance in professional practice. This methodological strategy allowed the learner to identify the organ in the simulator, using the image projection on the video beam as a reference, thereby integrating theoretical knowledge with practical experience.

3.1.3 Ways in which students acquire knowledge

In the training process, the students stated that they had used multiple strategies to acquire knowledge about biomedical equipment; their first approach dates back to the beginning of the career, while in the fourth semester it intensifies through practices in the clinical simulation center, an experience that is consolidated and prolonged in a sustained manner in the subsequent academic periods. Among the methodologies used, various practical and theoretical learning strategies were presented, which included the systematic manipulation of equipment and accessories, the application of tests on real or simulated patients and the incorporation of didactic resources such as instructional videos and scientific literature; additionally, the process was complemented with visual documentation (photographs and recordings) and the preparation of notes, which favored both the conceptual understanding and the consolidation of the knowledge acquired.

The students indicated that their knowledge of biomedical equipment was a progressive and multifaceted process. Initially, they had their first encounter in an academic setting through lectures that allowed them to physically identify and recognize the devices, such as the ultrasound machine. Subsequently, repeated interactions with this equipment in different contexts fostered the acquisition of practical knowledge, demonstrating that the frequency of contact influences the level of understanding and mastery. Finally, observing professionals at work in real-world settings proved to be a complementary and effective strategy, facilitating the acquisition of skills for the correct and safe use of biomedical technology. During hospital rotations, the students had their first experience with biomedical equipment widely used in clinical services such as emergency, gynecology, outpatient, and intensive care. This contact, complemented by simulation scenarios, included equipment such as the fetal Doppler, vital signs monitor, mechanical ventilator, blood pressure monitor, and defibrillator, among others. This early experience proved crucial to their training, providing them with the opportunity to acquire practical skills through direct manipulation and observation of professional use, thus establishing an essential foundation for the understanding and progressive mastery of more complex biomedical technologies. The integration of clinical simulation emerges as a pedagogical strategy that facilitates the transfer of theoretical knowledge to applied situations, fostering the development of professional competencies in a controlled environment with no risk to the patient.

3.1.4 Attitudinal dispositions that they manifest during their training process

Non-participant observations revealed that students' attitudes toward the use of biomedical equipment were not uniform, showing variations associated with the practice schedule. Thus, in the initial session held between 8:00 and 10:00 a.m., a greater collaborative attitude was observed, reflected in the voluntary assumption of patient roles to facilitate the practice of clinical skills by their peers. In contrast to less participative attitudes, some students demonstrated sustained attention to the professor's presentation, who simultaneously explained the procedure, manipulated the transducer, and took measurements on the simulated patient. This response revealed a marked cognitive engagement and a genuine interest in the practical training. During the practical session, a progressive transformation was observed in the students' attitude toward handling biomedical equipment, moving from limited participation to more active involvement. This change occurred after receiving detailed explanations, observing the professor's corrections, and having their questions answered, which fostered greater confidence and the acquisition of practical skills. This dynamic also demonstrated a high level of commitment from the participants, who remained attentive and close to the equipment, showing a receptive attitude toward the new developments that arose during the session. During the second session (10:00 am–12:00 pm), a significant reduction in student interest was evident, reflected both in the low accuracy of their answers to previously discussed questions and in multiple failures when handling the equipment, suggesting a negative impact on the understanding of the content presented.

3.1.5 But there are few opportunities to use the equipment in hospital environments

This topic addresses the challenges of learning about biomedical equipment among medical students, identifying a gap between their training and practical demands. Within this framework, two central themes are highlighted: the learning challenges and the strategies suggested by the students themselves to overcome them.

3.1.5.1 Learning Challenges

Ninth-semester students stated that the possibility of interacting with biomedical equipment in hospital settings is scarce, which restricts their educational experience and, consequently, may result in inadequate preparation to successfully meet the practical demands of clinical rotations. Students perceive limitations in the adequate availability of clinical accessories, such as electrocardiography electrodes and pulse oximeters, leading to unreliable records and potential errors in diagnostic interpretation. This difficulty highlights a persistent gap between theoretical instruction and practical experience in handling biomedical equipment, where the emphasis on the conceptual component precedes instrumental application. This restricts both the operational understanding of the equipment and the immediate transfer of acquired knowledge. During non-participant observations, inequality was noted in students' interaction with biomedical equipment, with only some having effective access to the devices. This asymmetry was particularly noticeable in the use of the ultrasound machine, as, in a five-minute interval, only one student was able to manipulate the transducer and perform the test on the patient. Frequent absences from class, along with a lack of concentration during sessions, are recognized as limiting factors in learning, as these behaviors restrict *content acquisition* and increase the risk of omitting information fundamental to academic training. Observations revealed that physical and mental fatigue, present in both students and professors, negatively impacted the pedagogical dynamic, as lengthy sessions generated evident tiredness that reduced student concentration and limited the effectiveness of the faculty in conducting practical exercises. Finally, students stated that some of the methodologies used by professors in teaching about biomedical equipment lack clarity, as they prioritize explaining the patient's physiological processes over instruction on the correct use of these devices.

3.1.5.2 Strategies suggested by the students themselves to overcome them

In the field of medical training, students recognize the need to optimize learning strategies related to the use of biomedical equipment; in this sense, they point out that practical interaction is a resource of special value, since the direct manipulation of the equipment not only facilitates familiarization with its components and accessories, but also promotes a deeper understanding of its operating principles. In medical training, the instructor's guidance is crucial. By providing precise explanations on the handling, operation, and care of equipment, they not only promote its proper use but also strengthen the understanding of its operating principles. Similarly, students emphasize the importance of early exposure to this equipment, as this initial familiarization allows them to explore its technical characteristics and gain experience before encountering real clinical scenarios. This preparation is complemented by prior reading of specialized literature, a practice that optimizes knowledge assimilation and enriches the experience in both practical classes and hospital rotations. It is important to highlight the need to address specific operational aspects—such as powering on, connections, cleaning, and immediate troubleshooting—as these not only foster a more comprehensive understanding of how the equipment works but also optimize its practical use in professional settings. The students positively valued the incorporation of dynamic pedagogical strategies, particularly playful activities such as interactive games related to biomedical equipment. These activities not only fostered a participatory environment but also facilitated the understanding and consolidation of the concepts covered. The inclusion of authentic audiovisual material illustrating the proper handling of biomedical equipment was recognized as a valuable resource, as it offers simulated practice that facilitates the transfer of skills to real clinical settings. The student proposal emphasizes the need to incorporate multidisciplinary training that integrates the experience of specialized professionals, particularly biomedical engineers, in order to enrich the teaching and provide a practical and in-depth understanding of the equipment that will be crucial in their professional practice.

3.1.6 A virtual environment to overcome this problem

This action research project aimed to strengthen training in the use and operation of biomedical equipment by creating a virtual learning environment. While students had previous experience with platforms such as Moodle, E-Programas, E-Anatomy, and I-MAIOS, they indicated that these were not very intuitive and were far removed from clinical practice, thus limiting their impact on learning. Given this deficiency, the proposal for a specific environment focused on biomedical equipment was positively received as an easily accessible training supplement, useful for integrating theoretical and practical content, not intended to replace in-person learning, but rather to enrich it during intermediate study periods. The students suggested that incorporating videos into virtual learning environments is an effective strategy for strengthening training in the use of biomedical equipment, as these resources allow for a precise visual representation of complex procedures and concepts, thus enhancing comprehension. Furthermore, their flexible and accessible nature facilitates independent study at different times and locations, while the interaction and multisensory stimulation they offer enhance both the assimilation and retention of knowledge. The students emphasized the need for virtual learning environments focused on biomedical equipment to be designed with a didactic approach, incorporating engaging resources that foster student motivation and commitment. By associating content with positive experiences, these resources contribute to both knowledge retention and active participation through interaction. They also highlighted the importance of including multimedia materials and simulations that replicate authentic clinical scenarios, which would facilitate understanding the use of equipment in healthcare settings without requiring physical presence in hospitals or clinics.

3.2 Design Phase

Table 2 presents the findings obtained in this research, developed through the application of the ADDIE methodology in its design stage and complemented with an action research cycle oriented to the analysis of a virtual training environment in biomedical teams.

4. Discussion

The use and understanding of biomedical equipment remains an underexplored area within medical training, despite its relevance to clinical practice. In this context, the present research aimed to analyze how medical students learn the use and operation of this equipment throughout their training. The findings suggest that a combination of pedagogical strategies—such as progressive teaching, experimental practice, direct manipulation, observation of professionals, and multidisciplinary work—promotes the gradual understanding of biomedical equipment in clinical simulation scenarios. Qualitative analysis identified a progressive learning process, evolving from an initial approach focused on observation and functional understanding to greater practical interaction in later stages of training. This process is consistent with Bruner's spiral learning theory (12), according to which knowledge is built cumulatively, progressively integrating new levels of complexity. Likewise, recurrent exposure to the handling of biomedical equipment emerges as a relevant element in the consolidation of learning, even in early stages of the career, which coincides with studies that highlight the need to combine observation and systematic training in the teaching of medical devices (13).

Table 2. Action research cycle in the Design phase.

CYCLE	ACTIVITY
Plan	In this stage, the learning outcomes of the virtual environment were established, based on the previous analysis; from this, the technical and conceptual resources were chosen, the relevant topics and subtopics were delimited, and finally, the course structure was configured, organized into modules with a coherent didactic

	sequence.
Act	The design tables of the virtual learning environment are presented, in which the developed pedagogical materials are consolidated, such as videos, presentations, readings and various digital resources; in addition, interactive activities, applied exercises and evaluation mechanisms through questionnaires and tests were structured.
Notice	A critical review of the interface design of the virtual learning environment on biomedical equipment was carried out, with the purpose of describing its structure, assessing its functionality and offering recommendations that favor both the usability and the training effectiveness of the available resources.
Reflect	In this phase, a comprehensive review of the design was carried out, based on the observations and feedback obtained, which allowed adjustments to be made to the content, activities and interface, in order to respond accurately to the needs detected.

Another relevant finding is the students' perception of a gap between theory and practice when these components are addressed in isolation. The simultaneous integration of both during clinical simulation sessions emerges as a factor that favors the understanding of the operating principles and their application in clinical contexts, in line with previous research in areas such as nursing and surgical instrumentation, which underscores the value of a continuous theoretical-practical pedagogical approach for strengthening clinical skills and managing risks associated with the use of medical devices (14-15).

The quantitative results of the study serve a descriptive and complementary role to the qualitative analysis, allowing for a more comprehensive understanding of the training process, without aiming to demonstrate statistically significant effects. In this sense, the observed trends should be interpreted with caution and not as causal or generalizable evidence of improvement in the correct use or safety of biomedical equipment. Among the main limitations of the study are the potential social desirability bias in the students' responses, the absence of a control group, and the novelty effect associated with the implementation of clinical simulation. These threats to internal validity reinforce the need to interpret the findings from a prudent and contextualized perspective, and open the possibility of future studies with comparative or longitudinal designs that delve deeper into the analysis of learning to use biomedical equipment in medical training.

Implications for medical education

Although this study was conducted within a specific institutional context, its contribution extends beyond the description of a local experience. From an action-research perspective, the findings allow for the identification of relevant pedagogical principles for teaching the use and operation of biomedical equipment in medical education, such as the importance of direct equipment handling, the simultaneous integration of theory and practice, faculty support during clinical simulation, and the incorporation of multidisciplinary approaches. These elements are not exclusive to the studied context but can be adapted and transferred to other medical training programs that include clinical simulation scenarios or similar learning environments.

Limitations

This study has some limitations. As it is a qualitative action research study conducted in a specific clinical simulation context with a small number of participants, the results are not generalizable to all medical programs. Furthermore, learning metrics and quantitative results were not incorporated to evaluate the effectiveness of the proposed strategies, given the methodological approach adopted. Therefore, it is suggested that future research include quantitative or mixedmethods designs, as well as the exploration of other simulation environments, to assess the impact of these strategies and analyze the transferability of the findings.

5. Conclusions

- The gradual incorporation of biomedical equipment into medical training, accompanied by frequent interaction with it, constitutes a relevant strategy to consolidate learning about its operation and proper use.
- However, even when diverse pedagogical approaches are applied, the risk remains that students will face a gap between theoretical knowledge and its practical application, which limits the strengthening of the skills needed to perform effectively in real clinical settings.

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